Chapter 13. The Stars

• Astronomers can directly observe only stars' positions, brightness, and spectra. The results are then used to determine the distances, motions, temperatures, and luminosities of stars.

Distance and Motion

• Distance is one of the most important stellar properties. Only if we know the distance to a star can we determine the intrinsic brightness of the star.

• As the Earth orbits around the Sun, the position of a nearby star appears to move back and forth against distant background stars over a six-month period. *Parallax* (p), defined as half of the total angular shift, is inversely proportional to the distance d. $d = 1/p$, with d measured in pc and p in seconds of arc. 1 pc = 3.26 light year = 3.09×10^{13} km.

• The closest star to the Sun is Proxima Centauri, which has a parallax of $0.772''$ and a distance of 1.3 pc. The smallest measurable parallax is $0.02''$ from ground, and $0.002''$ from space. We can measure parallaxes to determine distances only for stars within 500 pc.

• The *space velocity* of a star includes both speed and direction. It can be projected into two components: the tangential velocity across the line of sight, and the radial velocity along the line of sight. The motion of a star across the line of sight is called the *proper motion*. The radial velocity of a star is determined from the Doppler shifts of its spectral lines.

Brightnesses

• The brightness of a star is often expressed in *magnitudes*. In 130 B.C., Hipparchus divided the stars into six magnitudes, now called *apparent magnitudes*. The 1st magnitude stars are roughly 100 times brighter than the 6th.

• The brightness of a star could be measured with eyes, photographic plates or electronic detectors through different filters, such as filters centered at ultraviolet (U), blue (B), and visual (V).

• The apparent brightness of a star depends on the inverse square of its distance.
Apparent brightness $\propto 1/(\text{distance})^2$.

• The apparent magnitude, m, of a star depends on its luminosity as well as its distance, d. *Absolute magnitude*, M, is defined as the apparent magnitude of a star if it were places at a distance of 10 pc.
$M = m + 5 - 5\ log\ d$.

Stellar Spectra and Spectral Sequence

• Spectra of stars usually show specific patterns that can be classified into the *spectral sequence* OBAFGKM. (Oh, Be A Fine Guy/Gal, Kiss Me.)

• Annie J. Cannon decimalized the spectral classification system, and Cecilia Payne-Gaposchkin showed that the spectral sequence is caused by temperature-dependent ionization and excitation.

• The spectral sequence is a temperature sequence, as well as a color sequence.

Hertzsprung-Russell Diagram (HR Diagram)

• Hertzsprung and Russell independently plotted absolute visual magnitude (brightness) against spectral class for a large number of stars and found most stars lie on a band. The plot is called *HR diagram*, and the band is called the *main sequence*. Main sequence stars are called *dwarfs*.

• A star emits like a blackbody, so its luminosity $L = 4\pi R^2 \sigma T^4$, where R is the radius and T is the temperature (of the photosphere). Stars with large radii are luminous and are called *giants* and *supergiants*. Some stars are as hot as O main sequence stars but much fainter; these stars must have smaller radii and are called *white dwarfs*.

• The spectral line widths of a star depends on the star's surface gravity; large radius → lower surface gravity → narrower lines. Spectral line widths of stars can thus be used to determine luminosity classes.

• Morgan, Keenan, and Kellman divided the HR diagram into *luminosity classes*, using Roman numeral I for supergiants, III for giants, and V for main sequence dwarfs. The Sun is a G2 V star.

• We can take the spectrum of a star to determine its spectral and luminosity class, which in turn tells us the absolute magnitude of the star. We can also measure the apparent magnitude of the star. The distance to the star can be determined by comparing its apparent magnitude to absolute magnitude.

• The vast majority of stars ($\sim 70\%$) in the Galaxy are M dwarfs. The bright B stars contribute to the light of the disk of the Galaxy, but account for only $\sim 0.1\%$ of all the stars.

Stellar Masses

• Observations of binary stars provide us the most important of all stellar parameters, mass, through Kepler's laws. $(M_A + M_B) = a^3/P^2$.

• The masses measured from binary stars reveal the mass-luminosity relation for the main sequence stars. Stellar luminosity is proportional to $(\text{mass})^{3.5}$, or $L \propto M^{3.5}$.

• All main sequence stars produce energy by fusing H into He. Massive stars consume their fuel faster, hence have a shorter lifetime. The lowest mass of a star is about 0.08 $M_\odot$.

Distribution

• The Galaxy consists of a flat *galactic disk*, a sparsely populated spherical *galactic halo*, and a dense *galactic bulge*. The halo is populated mostly with lower mass red stars with low metal abundances. The bulge is dominated by lower mass red stars with a range of metallicity. Massive stars are found only in the galactic disk, giving it a bluish color.

• Two types of clusters are usually seen: *open clusters* and *globular clusters*. Open clusters are not as highly concentrated, hence can be more easily disrupted by tidal effects than globular clusters.

• Open clusters are younger, and their HR diagram is dominated by a main sequence. Globular clusters are older; their HR diagram has a shorter main sequence, and additionally a prominent giant branch, and a horizontal branch.

• Distances to clusters can be determined using the procedure of *main-sequence fitting*.